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UNITED STATES PATENT APPLICATION

FOR

METHODS, APPARATUS, AND SYSTEMS FOR MULTIPLE STIMULATION FROM A SINGLE STIMULATOR

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DESCRIPTION OF THE INVENTION

Field of the Invention

[001] The present invention relates to cardiac stimulators, and in particular, to methods, apparatus, and systems for pacing multiple sites in a heart.

Background

[002] During a normal heartbeat, the heart contracts in a coordinated fashion to pump blood. In particular, the heart contracts based on rhythmic electrical impulses, which are spread over the heart using specialized fibers. These rhythmic electrical pulses are initiated by the heart's natural pacemaker called the sinoatrial node ("SA node"). The SA node initiates electrical impulses to cause the right and left atrium to contract. As the atria contract, the electrical impulses from the SA node propagate to the atrial-ventricular node ("AV node"). After an inherent delay in the AV node, the AV node then transmits the electrical impulses, which eventually causes contraction in the right and left ventricles. The inherent delay of the AV node is known as the A-V delay and allows the atria to fully contract and fill the ventricles with blood. Blood from the ventricles then flows out of the heart and to the rest of the body. Therefore, the heart relies upon a rhythmic cycle of electrical impulses to pump blood efficiently.

[003] A heart may suffer from one or more cardiac defects that interfere with the rhythmic cycle or conduction of electrical impulses. For example, one known heart condition is an AV nodal block. An AV nodal block inhibits transfer of impulses from the SA node to the AV node, and thus, inhibits or prevents contraction of the

right and left ventricles. Other conditions, such as myocardial scarring and bundle branch block, may slow conduction of impulses, and thus, cause the heart to beat in an uncoordinated fashion.

[004] In diseased hearts having conduction defects and in congestive heart failure (CHF), cardiac depolarizations that naturally occur in one upper or lower heart chamber are not conducted in a timely fashion either within the heart chamber or to the other upper or lower heart chamber. In such cases, the right and left heart chambers do not contract in optimum synchrony with one another, and cardiac output suffers.

[005] Typically, an artificial pacemaker is installed to treat these and other various cardiac deficiencies. For example, in the case of loss of A-V synchrony, a single chamber, demand pacemaker may sense impulses from the SA node and then supply stimulating electrical pulses to the ventricles to cause contraction in the right and left ventricles. In this manner, an artificial pacemaker may compensate for blocked or slowed conduction of electrical impulses from the atrium to the ventricles in the heart.

[006] Dual chamber, demand pacemakers typically supply pacing pulses when required to one upper heart chamber and to one lower heart chamber, usually the right atrium and the right ventricle. In a dual chamber, demand pacemaker operating in DDD pacing mode, an atrial pacing pulse is delivered to the atrium if an atrial contraction is not sensed within an atrial escape interval (A—A interval) and a ventricular pacing pulse is delivered to the ventricle if a ventricular contraction is not sensed within a ventricular escape interval (V—V interval).

[007] Patients suffering from congestive heart failure and other conduction defects may require bi-ventricular and/or bi-atrial pacing. For example, in a dual chamber bi-atrial pacemaker, the right atrium may be paced at the expiration of an A—A escape interval, and the left atrium is synchronously paced or paced after a short delay. In a dual chamber bi-ventricular pacemaker, the right ventricle may be paced at the expiration of a V—V escape interval, and the left ventricle is synchronously paced or paced after a short delay time. In a single chamber pacemaker with bi-chamber pacing, a pacing pulse delivered at the end of an AV delay may trigger the simultaneous or slightly delayed delivery of the pacing pulse to the other heart chamber.

[008] In order to provide stimulating electrical pulses, known artificial pacemakers may include multiple stimulators. Furthermore, an artificial pacemaker may include multiple stimulators that are triggered at different times to provide dual chamber and/or bi-chamber pacing. Unfortunately, providing and controlling multiple stimulators increases the number of components that may fail within an artificial pacemaker.

[009] Accordingly, it would be desirable to provide methods, apparatus, and systems, which can avoid using multiple stimulators and overcome other deficiencies in the prior art.

SUMMARY OF THE INVENTION

[010] In accordance with an aspect of the present invention, a dual chamber cardiac pacemaker comprises a first electrode, a second electrode, a signal generator, a first lead, a second lead, and a distributor circuit. The first electrode

electrically is coupled to an atrial chamber. The second electrode is electrically coupled to a ventricular chamber. The signal generator generates a sequential pair of electrical pacing pulses. The first lead is coupled to the signal generator and to the first electrode and the second lead is coupled to the signal generator and to the second electrode. The distributor circuit is connected between the first lead and the signal generator and between the second lead and the signal generator. The distributor circuit receives the pair of electrical pacing pulses, distributes a first pacing pulse from the pair at a first amplitude to the first lead and distributes a second pacing pulse from the pair at a second amplitude to the second lead after a delay period.

[011] In accordance with another aspect of the present invention, a bi-chamber cardiac pacemaker comprises a first electrode, a second electrode, and a lead. The first electrode is electrically coupled to a left chamber and the second electrode is electrically coupled to a right chamber. The signal generator generates pacing pulses. The lead couples the signal generator to the first electrode and includes a distal end to be coupled to the second electrode. The lead further includes a delay element between the first electrode and the second electrode. The delay element prevents the second electrode from receiving a pacing pulse until after a predetermined delay period.

[012] In accordance with another aspect of the present invention, a bi-chamber cardiac pacemaker comprises a first electrode, a second electrode, a signal generator, a first lead, a second lead, and a distributor circuit. The first electrode is electrically coupled to a left chamber. The second electrode is

electrically coupled to a right chamber. The signal generator generates a sequential pair of electrical pacing pulses. The first lead couples the signal generator and the first electrode. The second lead couples the signal generator and the second electrode. The distributor circuit is connected between the first lead and the signal generator and between the second lead and the signal generator. The distributor circuit receives the pair of electrical pacing pulses, distributes a first pacing pulse of the pair at a first amplitude to the first lead, and distributes a second pacing pulse of the pair at a second amplitude to the second lead after a delay period.

[013] In accordance with yet another aspect of the present invention, a bi-chamber cardiac pacemaker comprises a first electrode, a second electrode, a signal generator, a first lead, a second lead, and a distributor circuit. The first electrode electrically is coupled to a left chamber and the second electrode is electrically coupled to a right chamber. The signal generator generates an electrical pulse. The first lead couples the signal generator and the first electrode. The second lead couples the signal generator and the second electrode. The distributor circuit is connected between the first lead and the signal generator and between the second lead and the signal generator. The distributor circuit distributes pacing pulses to the first lead at a first amplitude and to the second lead at a second amplitude in response to the electrical pulse generated by the signal generator.

[014] Additional features and advantages of the invention will be set forth in part in the description which follows, and in part will be obvious from the description, or may be learned by practice of the invention. The features and advantages of the

invention will be realized and attained by means of the elements and combinations particularly pointed out in the appended claims.

[015] It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are not restrictive of the invention, as claimed.

BRIEF DESCRIPTION OF THE DRAWINGS

[016] The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments of the invention and together with the description, serve to explain the principles of the invention. In the figures:

[017] Fig. 1 illustrates an environment in which methods, apparatus, and systems may be applied consistent with the principles of the present invention;

[018] Fig. 2 illustrates a functional block diagram of a controller with multiple leads for controlling contraction of a heart consistent with the principles of the present invention;

[019] Fig. 3 illustrates an example of a controller with multiple leads having internal delay elements consistent with the principles of the present invention;

[020] Fig. 4 illustrates a block diagram of an embodiment of a controller that includes multiple leads with respective clamping circuits consistent with the principles of the present invention;

[021] Fig. 5 illustrates a functional block diagram of a controller having a single lead with multiple wires consistent with the principles of the present invention;

[022] Fig. 6 illustrates an example of a distributor consistent with the principles of the present invention;

[023] Fig. 7 illustrates another example of a distributor consistent with the principles of the present invention;

[024] Fig. 8 illustrates another example of a distributor consistent with the principles of the present invention; and

[025] Fig. 9 illustrates a block diagram of a signal generator that includes a clamping circuit consistent with the principles of the present invention.

DESCRIPTION OF THE EMBODIMENTS

[026] Methods, apparatus, and systems are provided to control contraction of the heart. In particular, a controller is provided with a distributor that is configured to distribute stimulating signals to multiple sites in a heart via one or more leads. In addition, the controller may vary the timing of the stimulating signals such that stimulation of the multiple sites in the heart occurs with a delay. Methods, apparatus, and systems consistent with the present invention may provide dual chamber pacing (for example, DDD or DDI), bi-chamber pacing (i.e., bi-ventricular or bi-atrial), multiple stimulation to a single chamber, or any desired combination of these pacing modalities.

[027] Reference will now be made in detail to exemplary embodiments of the invention, examples of which are illustrated in the accompanying drawings. Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like parts.

[028] Fig. 1 illustrates an environment in which methods, apparatus, and systems may be applied consistent with the principles of the present invention. As shown, a controller 104 may accompany a heart 102. In addition, heart 102 is

shown with a superior vena cava 106, a right atrium 108, a left atrium 110, a right ventricle 112, a left ventricle 114, a sinoatrial node ("SA node") 116, an atrial-ventricular node ("AV node") 118, a Bundle of His 120, a right bundle branch 122, a left bundle branch 124, and Purkinje fibers 126.

[029] Heart 102 normally contracts in two stages based on sinus rhythm. Sinus rhythm is where heart 102 contracts in response to electrical impulses generated from SA node 116. In order to cause contraction in the cardiac muscle of heart 102, the electrical impulses from SA node 116 must depolarize the muscle fibers above a threshold voltage of approximately -80 mV.

[030] In particular, as electrical impulses propagate from SA node 116 to AV node 118, right atrium 108 and left atrium 110 contract. AV node 118 may then provide an AV delay of approximately 120 to 200 milliseconds that allows right ventricle 112 and left ventricle 114 to fill with blood.

[031] After the AV delay, AV node 118 then emits another electrical impulse. This electrical impulse propagates relatively quickly over heart 102 down Bundle of His 120, and over right bundle branch 122, left bundle branch 124, and Purkinje fibers 126. In response, cardiac muscles in right ventricle 112 and left ventricle 114 depolarize and contract to pump blood to the rest of the body (not shown).

[032] Controller 104 assists heart 102 to contract in a coordinated fashion based, for example, on sinus rhythm. Controller 104 may assist heart 102 by applying one or more electrical pulses to one or more sites in heart 102 and cause contraction in the chambers of heart 102, such as right ventricle 112 and left ventricle 114. Controller 104 may vary the timing that the stimulating electrical

pulses are applied to heart 102. In addition, controller 104 may be configured to selectively apply the stimulating electrical pulses to one or more of the sites in heart 102.

[033] As shown in Fig. 1, controller 104 may be coupled to heart 102 using leads 128 and 129. Leads 128 and 129 may be installed endocardially into heart 102 via superior vena cava 106 using known surgical procedures. Leads 128 and 129 may be implemented as a hollow catheter made of an insulating material, such as silicone rubber, and include one or more connection paths made of a conductive material, such as a wire made of stainless steel or other metal. The one or more connection paths of leads 128 and 129 may carry signals back and forth between heart 102 and controller 104. For example, the one or more connection paths of leads 128 and 129 may carry signals that represent the electrical activity of heart 102 from heart 102 to controller 104. In addition, the one or more connection paths of leads 128 and 129 may carry electrical signals, such as stimulating electrical pulses, from controller 104 to heart 102.

[034] For example, in one embodiment, lead 128 may be structured to include an atrial lead branch 130, an atrial electrode 132, a right ventricle lead branch 134, and a right ventricle electrode 136. Lead 129 may be structured to include a left ventricle lead branch 138 and a left ventricle electrode 140. Although Fig. 1 illustrates two leads (i.e., leads 128 and 129), any number of leads may be used to couple controller 104 to heart 102. In addition, each lead may include any number of connection paths, e.g., wires.

[035] Atrial lead branch 130 of lead 128 provides a connection path between controller 104 and right atrium 108 for carrying signals associated with right atrium 108 and SA node 116 from heart 102 to controller 104 and for carrying stimulating electrical signals from controller 104 to heart 102. Although atrial lead branch 130 is shown as a branch of lead 128, atrial lead branch 130 may be implemented using a separate lead from controller 104.

[036] Atrial electrode 132 is provided at the tip of atrial lead branch 130 and physically contacts one or more sites in right atrium 108. Atrial electrode 132 senses the electrical activity in heart 102 associated with right atrium 108 and SA node 116. In addition, atrial electrode 132 delivers the stimulating electrical signals from controller 104 to right atrium 108. Atrial electrode 132 may be implemented, for example, as a helical coil of wire made of a metal, such as stainless steel. Atrial electrode 132 may be implemented using other known structures and may also comprise a plurality of electrodes.

[037] Right ventricle lead branch 134 of lead 128 provides a connection path for carrying signals associated with right ventricle 112 from heart 102 to controller 104 and for carrying stimulating electrical signals from controller 104 to right ventricle 112. Although right ventricle lead branch 134 is shown as a branch of lead 128, right ventricle lead branch 134 may be implemented using a separate lead from controller 104.

[038] Right ventricle electrode 136 is provided at the tip of right ventricle lead branch 132 and physically contacts one or more sites in right ventricle 112. Right ventricle electrode 136 senses the electrical activity in heart 102 associated with

right ventricle 112, such as electrical impulses from AV node 118 that are propagating over right bundle branch 122. In addition, right ventricle electrode 136 delivers the stimulating electrical signals from controller 104 to right ventricle 112. Right ventricle electrode 136 may be implemented, for example, as a helical coil of wire made of a metal, such as stainless steel. Right ventricle electrode 136 may be implemented using other known structures and may also comprise a plurality of electrodes.

[039] Left ventricle lead branch 138 of lead 129 provides a connection path for carrying signals associated with left ventricle 114 from heart 102 to controller 104 and for carrying electrical signals from controller 104 to left ventricle 114. Although left ventricle lead branch 138 is shown as a branch of lead 129, left ventricle lead branch 138 may also be implemented using a separate lead from controller 104.

[040] Left ventricle electrode 140 is provided at the tip of left ventricle lead branch 138 and physically contacts one or more sites in left ventricle 114. Left ventricle electrode 140 senses electrical activity in heart 102 associated with left ventricle 114, such as electrical impulses from AV node 118 that are propagating over left bundle branch 124. Left ventricle electrode 140 may be implemented, for example, as a helical coil of wire made of a metal, such as stainless steel. Left ventricle electrode 140 may be implemented using other known structures and may also comprise a plurality of electrodes.

[041] The lead configuration illustrated in Fig. 1 is but one example for providing bi-chamber stimulation. One of ordinary skill will appreciate that methods, systems, and apparatus consistent with the present invention may use any lead

configuration that allows for stimulation of any combination of chambers or sites in heart 102. By way of example only, the leads of controller 104 could provide for sensing and/or pacing in (1) right ventricle 112 and right atrium 108, (2) left ventricle 114 and left atrium 110, (3) right ventricle 112 and left ventricle 114, (4) the right and left atria 108 and 110, respectively, (5) two sites in a single chamber, such as left ventricle 114, or any combination of the above.

[042] Fig. 2 illustrates a functional block diagram of controller 104 with multiple leads for controlling contraction of heart 102 consistent with the principles of the present invention. As shown, controller 104 includes sense amplifiers 200, 202, and 204, a processor 206, a memory 208, a telemetry module 210, a signal generator 212, and a distributor 214.

[043] Sense amplifiers 200, 202, and 204 are coupled via lead 128 to atrial electrode 132, right ventricle electrode 136, and left ventricle electrode 140, respectively. Sense amplifiers 200, 202, and 204 receive signals indicating electrical activity of heart 102 from their respective electrodes, amplify these signals, and provide them to processor 206. Sense amplifiers 200, 202, and 204 may be implemented using, for example, well known circuitry.

[044] Processor 206 receives and monitors signals from sense amplifiers 200, 202, and 204 and generates one or more control signals. For example, processor 206 may detect the sinus rhythm of heart 102 based on signals received from atrial electrode 132. Processor 308 may then monitor the electrical activity of right ventricle 112 and left ventricle 114 based on signals received from right ventricle electrode 136 and left ventricle electrode 140. If the electrical activity in

right ventricle 112 fails to reach a threshold level within a period of time corresponding, for example, to a desired A—V delay period, then processor 206 may be configured to provide one or more control signals to signal generator 212. The one or more control signals then command signal generator 212 to deliver one or more stimulating electrical pacing pulses to chambers of heart 102, such as right ventricle 112 and/or left ventricle 114.

[045] Alternatively, processor 206 may be configured to provide the one or more control signals to signal generator 212 automatically. For example, upon detecting the sinus rhythm of heart 102 based on signals received from atrial electrode 132, processor 206 may be configured to automatically provide the one or more control signals that commands signal generator 212 to stimulate one or more chambers of heart 102, such as right ventricle 112 and left ventricle 114, automatically.

[046] Processor 206 may be implemented using known devices. For example, processor 206 may be implemented using a series of digital circuits or logic gates. Alternatively, processor 206 may be implemented using a microprocessor, such as those manufactured by the Intel Corporation.

[047] Memory 208 provides storage for information used by processor 206. For example, memory 208 may include instructions for configuring processor 206 and instructions for monitoring the electrical activity of heart 102. Memory 208 may be implemented using known types of memory, such as a random access memory and read-only memory.

[048] Telemetry module 210 provides diagnostic information indicating the performance of controller 104. For example, telemetry module 210 may transmit the signals received from sense amplifiers 200, 202, and 204, and signals generated by signal generator 212 via a radio link to another device, such as an external programmer (not shown). Telemetry module 210 may also collect and transmit other types of information. Telemetry module 210 may be implemented as a radio receiver/transmitter using a known radio frequency, such as 100 kHz.

[049] Signal generator 212 generates electrical pulses for treating heart 102, for example, via lead 128. The electrical pulses from signal generator 212 may be delivered to, for example, right ventricle 112 and left ventricle 114 respectively via right ventricle lead branch 134 and left ventricle lead branch 138 of lead 128. In particular, signal generator 212 may provide, for example, a cathodal pulse of 5 V for a duration of approximately 2 milliseconds to stimulate contraction in heart 102.

[050] When treating heart 102, signal generator 212 may vary the electrical pacing pulses delivered to heart 102. Signal generator 212 may vary the number of pulses, the pulse amplitude, and pulse width. For example, signal generator 212 may generate electrical pacing pulses in sequential pairs to stimulate contraction in one or more chambers of heart 102, such as right atrium 108 and right ventricle 112. Alternatively, signal generator 212 may manipulate the pulse amplitude and duration of its pulses in response to conditions measured from heart 102. Signal generator 212 may also use other types of pulses, such as biphasic pulses or anodal pulses, to stimulate contraction in heart 102.

[051] In one embodiment, signal generator 212 is implemented using known circuitry, such as "one-shot" circuitry, that is triggered by processor 206. Alternatively, signal generator 212 may be implemented using other known components, such as a capacitor coupled to a continuous charger.

[052] Distributor 214 receives the electrical pacing pulses from signal generator 212 and, in response, distributes the one or more electrical pacing pulses to one or more chambers of heart 102, such as right ventricle 112, left ventricle 114, etc., based on one or more control signals from processor 206. When distributing pulses, distributor 214 may vary the delay time between pulses, or inhibit one or more of the pulses based on the control signals from processor 206. One skilled in the art would also recognize that distributor 214 may vary other characteristics of the pulses, such as the amplitude, based on the control signals from processor 206.

[053] Distributor 214 may be configured in various ways to manipulate the distribution of the electrical pulses to heart 102. For example, distributor 214 may be implemented using a variety of circuits and digital logic, such as flip-flops, multiplexers, Schmidt triggers, etc. Various examples of distributor 214 are described in more detail with reference to Figs. 6-8.

[054] Fig. 3 illustrates a block diagram of one embodiment of controller 104 having multiple leads that include internal delay elements consistent with the principles of the present invention. In particular, delay elements 300 and 302 are shown within leads 128 and 129 respectively. Upon receiving electrical pacing pulses, delay elements 300 and 302 may delay the delivery of these pulses between right ventricle 112 and left ventricle 114, or between right atrium 108 and right

ventricle 112, etc. In one embodiment, delay elements 300 and 302 are implemented as inductive elements to delay the delivery of pulses. One skilled in the art would also recognize that other types of components may be used within delay 300 and 302 to delay the delivery of pulses.

[055] Fig. 4 illustrates a block diagram of an embodiment of controller 104 that includes multiple leads with respective clamping circuits consistent with the principles of the present invention. As shown, controller 104 may include clamping circuits 400a and 400b at the output of distributor 214. Clamping circuits 400a-b allow controller 104 to selectively suppress or clamp the one or more electrical pacing pulses as they are output from distributor 214 and thereby vary the amplitude of a pulse or altogether inhibit application of a pulse. Use of clamping circuits 400a-b may be useful when, for example, controller 104 has detected spontaneous depolarization in a chamber of heart 102.

[056] In particular, controller 104 may suppress or clamp the electrical pacing pulses when processor 206 detects spontaneous depolarization in heart 102 and determines that heart 102 does not require assistance based on signals received from electrodes 132, 136, and 140. The signals from electrodes 132, 136, and 140 may also indicate that the electrical impulses of sinus rhythm in heart 102 are propagating normally. Accordingly, processor 206 may send one or more control signals to clamping circuits 400a and/or 400b. In response, camping circuits 400a-b may then alter or suppress electrical pacing pulses output from distributor 214. Although clamping circuits 400a-b are shown connected at the output of distributor 214, clamping circuits 400a-b may be installed anywhere in

controller 104, such as between signal generator 212 and distributor 214. Clamping circuits 400a-b are also described in more detail with reference to Fig. 9

[057] Fig. 5 shows a block diagram of one embodiment of controller 104 having a single lead with multiple wires consistent with the principles of the present invention. In particular, controller 104 is coupled to heart 102 via a single lead, i.e., lead 128 instead of multiple leads as shown in Figs. 1-4. In this embodiment, lead 128 further includes multiple wires, such as wires 500 and 502. Wires 500 and 502 provide respective connection paths to sites within heart 102, such as sites within right atrium 108, right ventricle 112 and/or left ventricle 114. Although Fig. 5 illustrates two wires within lead 128, i.e., wires 500 and 502, lead 128 may include any number of wires. Wires 500 and 502 may be constructed from known conductive materials, such as stainless steel, copper, or other metal. One skilled in the art would also recognize when controller 104 should be implemented with one lead having multiple wires or with multiple leads.

[058] Fig. 6 illustrates an example of distributor 214 consistent with the principles of the present invention. As shown in Fig. 6, distributor 214 may be implemented as a bistable flip-flop that is triggered by one or more signals from signal generator 212. In particular, one or more signals from signal generator 212 are received at inputs 600 and 602. Capacitors 604 and 606 are coupled to inputs 600 and 602 respectively and charge and discharge in response to the one or more signals. The charge/discharge of capacitors 604 and 606 cause transistors 608 and 610 to turn on and then off. The cycling of transistors 608 and 610 subsequently generate electrical pacing pulses at outputs 612 and 614. Outputs 612 and 614 are

then coupled to lead 128 and/or lead 129 to provide the electrical pacing pulses to one or more chambers of heart 102. Alternatively, when controller 104 is implemented with a single lead as shown in Fig. 5, outputs 612 and 614 may be coupled to wires 500 and 502 to provide the electrical pacing pulses to heart 102.

[059] The characteristics of the electrical pacing pulses, such as their amplitude and pulse width, are determined based on the values of resistors 616, 618, 620, 622, and 624 and capacitors 626 and 628. The values of these components may be predetermined. Alternatively, distributor 214 may manipulate or set one or more of these values in response to control signals from processor 206. Resistors 616, 618, 620, 622, and 624 and capacitors 626 and 628 are implemented using known components. Moreover, distributor 214 may manipulate the above components to control the delay between pulses.

[060] Fig. 7 illustrates another example of distributor 214 consistent with the principles of the present invention. As shown, distributor 214 may be implemented as an array of "LC" circuits comprising inductors 702, 704, and 706, and capacitors 708, 710, and 712. In particular, the signal from signal generator 212 may be used energize the LC circuits of distributor 214. In one embodiment, inductors 702, 704, and 706 may be set to a particular inductive value for a desired delay between electrical pacing pulses based on a control signal from processor 206. Processor 206 may determine the values for inductors 702, 704, and 706 based on information received via telemetry module 210.

[061] In order to trigger application of the electrical pacing pulses, distributor 214 may include diodes 716 and 718, which are biased based on the voltage output

of the LC circuits. For example, in one embodiment, diodes 716 and 718 may be implemented as Zener diodes that discharge when the respective LC circuits for diodes 716 and 718 reach a threshold voltage. Alternatively, diodes 716 and 718 may provide electrical pacing pulses based on a local electrical state of electrodes, such as electrodes 132, 136, and 140, within heart 102. In particular, diodes 716 and 718 may be implemented as silicon controlled rectifiers, which are gated based on control signals from processor 206. Processor 206 may generate the control signals in response to signals received from sense amplifiers 200, 202, and 204, which are coupled to electrodes 132, 136, and 140 respectively.

[062] Upon reaching the threshold voltage, diodes 716 and 718 then discharge electrical pacing pulses to outputs 720 and 722. Outputs 720 and 722 are then coupled to lead 128 and/or lead 129 to provide the one or more electrical pacing pulses to one or more chambers of heart 102. Alternatively, when controller 104 is implemented with a single lead as shown in Fig. 5, outputs 720 and 722 may be coupled to wires 500 and 502 to provide the electrical pacing pulses to heart 102. One skilled in the art would also recognize that distributor 214 may vary the amplitude of the electrical pulses using, for example, known circuitry (not shown) or provide the electrical pulses at a single amplitude, for example, by implementing diodes 716 and 718 as Zener diodes.

[063] Fig. 8 illustrates another exemplary distributor 214 consistent with the principles of the present invention. As shown, distributor 214 may include a switching element 800 that routes the one or more electrical pulses from signal generator 212 to leads 128 and 129. In addition, distributor 214 may also include

shunt resistors 802 and 804 to set the amplitude of pulses delivered to leads 128 and 129 respectively. The value of resistors 802 and 804 may, for example, be set in response to control signals from processor 206. Resistors 802 and 804 may be implemented using known components.

[064] Switching element 800 may be implemented using known components, such as transistors or thyristors. Alternatively, switching element 800 may include a unistable electronic switch, which is followed by a bistable flip-flop to distribute electrical pacing pulses to leads 128 and 129. When controller 104 is implemented with a single lead as shown in Fig. 5, one skilled in the art would also recognize that the output of switch 800 may be coupled to wires 500 and 502 to provide electrical pacing pulses to heart 102.

[065] Switching element 800 may distribute electrical pacing pulses based on a delay, for example, in response to control signals from processor 206. The delay may be a predetermined amount or specified by the one or more control signals from processor 206. In this embodiment, distributor 214 may also include other circuitry, such as a one-shot circuit (not shown) and threshold comparators, for example, to vary the delay between the pulses delivered to the right ventricle electrode 136 and left ventricle electrode 140.

[066] Fig. 9 illustrates an example of clamping circuits 400a-b consistent with the principles of the present invention. As described below, clamping circuit 400a (or 400b) clamps or suppresses a signal, such as the output of distributor 214, in response to a control signal (i.e., a clamping signal) from processor 206. As shown,

in one embodiment, clamping circuit 400a may include components, such as operational amplifiers 902, 904, 906, 908, and 910, and diodes 912 and 914.

[067] Clamping circuit 400a receives an input signal 916 from distributor 214 and a clamping signal 918 from processor 206. Input signal 916 is fed to operational amplifier 904, which is configured as a unity-gain buffer. The output of operational amplifier 904 is then fed to an input of operational amplifier 910 and the outputs of operational amplifiers 906 and 908 via diodes 914 and 912 respectively. The output of operational amplifier 904 is also fed back to inputs of operational amplifiers 906 and 908.

[068] Clamping signal 918 is fed to operational amplifier 902, which is also configured as a unity-gain buffer. The output of operation amplifier 902 is then provided to inputs of operational amplifiers 906 and 908. Operational amplifiers 906 and 908 operate in conjunction with diodes 914 and 912 to clamp or suppress input signal 916 based on the relative values for input signal 916 and clamping signal 918.

[069] For example, when input signal 916 is less than clamping signal 918, operational amplifiers 906 and 908 and diodes 914 and 912 are biased such that pacing signal 920 will be substantially the same value as input signal 916. Clamping circuit 900 then outputs pacing signal 920 from operational amplifier 910 to lead 128 and/or lead 129. However, when input signal 916 exceeds clamping signal 918, operational amplifiers 906 and 908 and diodes 914 and 912 are biased such that pacing signal 920 will be the same value as clamping signal 920.

[070] Accordingly, if clamping or suppression of electrical pacing pulses is desired, controller 104 may use processor 206 to send one or more control signals,

such as clamping signal 918, to clamping circuit 400a (or 400b). For example, if processor 206 decides to suppress one or more electrical pacing pulses from signal generator 212, processor 206 may set clamping signal 918 to an appropriate value, such as 0 volts. In addition, if processor 206 detects that heart 102 requires assistance, then processor 206 may set clamping signal 918 to an appropriate value, such as 5-10 volts, such that electrical pacing pulses pass through clamping circuit 400a.

[071] Other embodiments of the invention will be apparent to those skilled in the art from consideration of the specification and practice of the invention disclosed herein. For example, while one embodiment describes a three-chamber cardiac stimulation device, one of ordinary skill would appreciate that the present invention could be used in a four-chamber device, a two-chamber device, or even a single-chamber device having multiple intrachamber stimulation sites. Likewise, although Figs. 2-4 illustrate sense amplifiers 200, 202, and 204, systems, methods and apparatus consistent with the present invention may use any desired number of sense amplifiers 200, 202, and 204. It is intended that the specification and examples be considered as exemplary only, with a true scope and spirit of the invention being indicated by the following claims.